e-ISSN 1135-9250
EDUTEC. Revista Electrónica de Tecnología Educativa
Número 91 – Marzo 2025
Sección General

Theoretical Knowledge as a Bridge to Technological Integration: Empowering Educators with Virtual Worlds for Effective Teaching

La teoría como puente hacia la integración tecnológica: Empoderando a los educadores con mundos virtuales para una enseñanza efectiva

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ABSTRACT

This study examines how theoretical knowledge can serve as a bridge to the integration of Three-Dimensional Immersive Digital Environments (3D-IDE) and Virtual Worlds (VW) in teacher education. The rapid evolution of digital technologies presents new opportunities for enhancing pedagogical practices, but many educators face challenges in adopting these technologies due to a lack of digital competencies.

A qualitative longitudinal approach was applied, focusing on a course designed to introduce university teachers to the use of 3D-IDE and VW. Data was collected through thematic forums, final reflections, and course projects, using a combination of axial coding and thematic analysis to assess the progression of participants' skills and perspectives.

Participants exhibited significant improvement in their understanding of 3D-IDE, moving from initial skepticism to effective integration of these tools in their teaching practices. The study revealed that deep theoretical knowledge helped overcome technical challenges, fostering a critical perspective on the use of emerging technologies. The study highlights the importance of structured, supportive training that combines theoretical and practical elements. By bridging the gap between theory and practice, educators not only developed technical competencies but also transformed their pedagogical approaches, illustrating the potential of 3D-IDE to enrich the teaching-learning process.

RESUMEN

Este estudio examina cómo el conocimiento teórico serve como un puente para la integración de Entornos Digitales Inmersivos Tridimensionales (3D-IDE) y Mundos Virtuales (VW) en la formación docen-te. La rápida evolución de las tecnologías digitales presenta nuevas oportunidades para mejorar las prácticas pedagógicas.

Se diseño un curso para introducir al profesorado universitarios en el uso de 3D-IDE y VW. Se aplicó un enfoque cualitativo y longitudinal a través de foros temáticos, reflexiones finales y proyectos del curso, utilizando una combinación de codificación axial y análisis temático para evaluar la progresión de las habilidades y perspectivas de los participantes.

Los participantes mostraron una mejora significativa en su comprensión de los 3D-IDE, pasando del escepticismo inicial a una integración efectiva de estas herramientas en sus prácticas docentes. El estudio reveló que un conocimiento teórico profundo ayudó a superar los desafíos técnicos, fomentando una perspectiva crítica sobre el uso de tecnologías emergentes. El estudio subraya la importancia de una formación estructurada y de apoyo que combine elementos teóricos y prácticos. Al cerrar la brecha entre la teoría y la práctica, los educadores desarrollaron competencias técnicas, y transforman sus enfoques pedagógicos, ilustrando el potencial de los 3D-IDE para enriquecer el proceso de enseñanza-aprendizaje.

KEYWORDS - *PALABRAS CLAVE*

Immersive environments, virtual worlds, digital competence, teacher education

Entornos inmersivos, mundos virtuales, competencias digitales, formación docente

DOI: https://doi.org/10.21556/edutec.2025.91.3615

Received: 13-10-2024
Accepted: 28-02-2025

1. INTRODUCTION

The rapid evolution of digital technologies has catalysed transformative opportunities for pedagogical innovation. Among these advancements, Three-Dimensional Immersive Digital Environments (3D-IDEs) and Virtual Worlds (VWs) have emerged as potent tools capable of reshaping teaching and learning processes. Yet, despite their potential, the effective integration of such technologies into education remains a significant challenge. Educators often grapple with technical barriers, compounded by gaps in digital competencies or scepticism towards technology-driven approaches.

This study seeks to address this disconnect by examining how deep theoretical knowledge[1] can serve as a bridge between conceptual understanding and the practical adoption of 3D-IDEs and VWs in higher education. Central to this exploration is the research question: How can a robust grounding in educational theory facilitate the effective integration of 3D Immersive Digital Environments through virtual worlds in teacher training, particularly in overcoming initial technical limitations?

Adopting a qualitative longitudinal methodology, the research focuses on an intensive professional development course designed for university educators. The study posits that a nuanced understanding of educational theory not only demystifies technical complexities but also fosters educators' confidence in critically adapting these tools to their contexts.

The relevance of this work lies in its capacity to inform the design of forward-thinking teacher training programmes. By elucidating the transformative journey from theoretical knowledge to practical implementation, the findings aim to equip educators with the skills and mindset necessary to navigate the digital age. Ultimately, this research underscores the importance of theory as a catalyst for overcoming barriers, enabling the strategic and meaningful adoption of emerging technologies in education.

2. THEORETICAL FRAMEWORK

2.1. Three-Dimensional Immersive Digital Environments (3D-IDE) and Virtual Worlds (VW)

3D-IDE are virtual spaces created through digital technologies that allow users to immerse themselves and actively participate in a simulated reality (Godínes & Rueda, 2023; Marin et al., 2024). These environments are characterized by their ability to offer immersive experiences where users not only interact with the environment but also feel part of it. This type of immersion implies a dissolution of the subject in the virtual surface, creating an enveloping and

[1] The concept of "deep theoretical knowledge" in educational technology and neuroscience encompasses a multidisciplinary approach integrating insights from education, cognitive science, and neuroscience (Han et al., 2019; Feiler & Stabio, 2018). It involves understanding the neural dynamics of learning and teaching, including brain plasticity and adaptability (Pradeep et al., 2024). Deep learning in education emphasizes critical thinking and sustainable learning strategies (Kovač et al., 2023), while educational neuroscience explores conceptual change, error detection, and executive function in science learning (Vaughn et al., 2020). The field incorporates advanced technologies like brain-computer interfaces and neuroimaging to enhance learning experiences (Privitera & Du, 2022; Williamson, 2018).

multisensory experience. Immersion allows the subject to enter a created reality, blending with the environment (Godínes & Rueda, 2023). 3D-IDE encompasses the concepts of Virtual Reality (VR), Augmented Reality (AR), and VW (Ángel, 2020).

VW, which differ from other digital environments in their ability to realistically simulate physical environments and provide a space for social interaction and collaboration, allow users to create avatars and participate in shared activities and experiences within a persistent three-dimensional environment (Ángel, Valdés y Guzmán, 2017; Santoianni & Ciasullo, 2020). These offer high educational potential by allowing the simulation of complex situations, facilitating experiential, collaborative, and spatial learning (Badilla-Quintana & Sandoval-Henríquez, 2021).

In educational contexts, VW explore abstract and theoretical concepts in a tangible environment, practice skills in simulated scenarios, and collaborate with peers on interactive projects (Badilla-Quintana & Sandoval-Henríquez, 2021; Shorey & Ng, 2020). This promotes greater knowledge retention and the development of practical skills through activities that foster interactivity and active learning, adapting to the immersive characteristics of these environments (Mon et al., 2014; Zambrano et al., 2023). Therefore, their use has expanded to different disciplines such as language learning and culture in teacher training (Ciekanski et al., 2020; Zhang, 2020).

2.2. Digital teaching competencies

The integration of VW enhances teacher training through the development of digital teaching competencies (Badilla-Quintana & Sandoval-Henríquez, 2021; Jacka, 2021). Teachers must develop specific technical skills to use VR, AR, and Mixed Reality (MR) tools, including the creation and management of immersive content, as well as the creation of a digital social presence (Robertson et al., 2022). Training in these skills is crucial to ensure that teachers can effectively integrate VW into their teaching and provide high-quality learning experiences to their students (Tondeur et al., 2019; Zambrano et al., 2023).

The TPACK framework is a reference for teachers to effectively integrate digital technologies into their educational practice, combining technological, pedagogical, and content knowledge (Soza, 2020). At the same time, the cultural and generational aspect must be taken into account (Robertson et al., 2022), as well as access to digital technology professional learning, technical guidance, and a supportive school and policy environment (Ángel et al., 2017; Bower et al., 2020), as these impact the adoption and acceptance of these technologies.

The integration of 3D-IDE implies a change in traditional educational paradigms, promoting more dynamic and interactive teaching methods that actively involve students in their learning (Ángel et al., 2017). Continuous professional development is essential for teachers to stay updated with new technologies and methodologies, ensuring that they can effectively integrate 3D-IDE into their pedagogical practices (Mbonye, 2022; Soza, 2020). Some experiences of integrating VW for teacher training have had favorable results, but have also encountered challenges such as the learning curve faced by teachers and students when adapting to virtual environments, which requires time and resources for effective adoption (Ángel et al., 2017); at the same time, ethical and privacy aspects must be taken into account, ensuring data protection and the creation of safe environments for students (Zambrano et al., 2023).

2.3. Accessibility, Personalisation, and Formative Assessment: Core Principles for Effective Integration of 3D-IDEs

3D-IDEs hold transformative potential for education by merging pedagogical innovation with technological adaptability. Their ludic appeal and capacity to foster intrinsic motivation create fertile ground for holistic learning experiences, enabling students to engage with complex concepts through interactive simulations and problem-solving scenarios (Ángel Rueda et al., 2018). For instance, applications in fields like computer programming demonstrate how 3D-IDEs can simplify abstract topics through visual-spatial representations, enhancing conceptual mastery (López Solórzano & Ángel Rueda, 2023). However, their effectiveness hinges on accessibility and universal design principles, which ensure these environments cater to diverse learning needs. By embedding adaptive interfaces and personalised teaching services—such as adjustable difficulty levels or multimodal content delivery—3D-IDEs can democratise access while promoting 21st-century skills like digital literacy, creativity, and collaborative problem-solving (Luís, Rocha, & Marcelino, 2017; Mon & Cervera, 2014). This alignment between technical design and pedagogical inclusivity positions 3D-IDEs as tools not just for engagement, but for equitable educational advancement.

The pedagogical value of 3D-IDEs is further amplified through formative assessment mechanisms and intentional competency development. Immersive environments enable real-time feedback loops, such as virtual reality systems that track user interactions or AI-driven face recognition tools to gauge emotional engagement during inquiry-based tasks (Okada et al., 2019). These features allow educators to refine instructional strategies dynamically, addressing gaps in understanding before they solidify. Crucially, the success of these environments depends on user-centric design that prioritises pedagogical objectives over technological novelty. By grounding development in frameworks like Universal Design for Learning (UDL), 3D-IDEs transcend mere immersion to become scalable, inclusive platforms that balance usability with educational rigour (Pirker et al., 2013; Ciasullo, 2018).

3. METHOD

3.1. Context

The course "Design of a Didactic Model to Introduce Teachers to the Use of Virtual Worlds for Educational Purposes" was conducted at a Peruvian university with a sociodemographically diverse participant group. Notably, 92.86% of participants identified as women and 7.14% as men, while 78.57% came from private schools and 21.43% from public institutions. In terms of professional qualifications, 71.43% of the teachers held higher education credentials, and 28.57% had completed upper secondary education. The course aimed to train university teachers in the effective integration of 3D-IDE into their pedagogical practices, fostering innovation and continuous improvement in education. Over 10 weeks, it employed an active, student-centered methodology that combined practical training, collaborative learning, discussion forums, case studies, and a final project. These strategies were designed to ensure meaningful, contextually relevant learning that participants could adapt to their unique educational environments.

Throughout this course, participants had the opportunity to:

1. Gain comprehensive knowledge of 3D-IDE, including VR, AR, VW, MR, XR, and their historical and technological development.
2. Build technical skills for selecting and using digital tools to create immersive educational experiences in virtual worlds.
3. Apply a didactic model for teaching in 3D-IDE, integrating technological, pedagogical, and social contexts.
4. Design and deliver a didactic activity using the 3D-IDE model, showcasing the practical application of course knowledge.

Encourage collaboration and the sharing of best practices to enhance understanding and skills through peer learning. This course was conducted virtually with synchronous sessions once a week. Tools such as Blockade Labs, InstaVerse, FrameVR, Spatial, and Bezel were used. The tools were introduced gradually, as well as reflection on their integration in the pedagogical area.

3.2. Objectives

This research was based on the research question: How can profound theoretical knowledge in education facilitate the effective integration of 3D-IDE technologies through VW in teacher education, overcoming initial technical limitations? The general objective is to examine the role of theoretical knowledge in facilitating the adoption and effective use of 3D-IDE technologies through VW by educators with advanced training but limited digital competencies. To this end, four specific objectives have been broken down:

1. Identify the main technical barriers that educators face when integrating VW into their teaching practices, and explore how existing theoretical knowledge can be applied to overcome these barriers.
2. Evaluate the effects of integrating VW in teaching, focused on improving the educational experience for both educators and students.
3. Document educators' experiences and perceptions on the use of VW after a training process focused on theoretical knowledge.

A qualitative longitudinal methodology was used. For data collection, the content of responses in thematic forums and final reflections of teachers in training was analyzed.

3.3. Data Analysis

An analysis of educational discourse was carried out that is not limited to the document and verbalization, but takes into consideration other elements that configure the educational, such as activities, distribution of spaces and times (Buenfil, 1993), for example, in virtual contexts. An exhaustive reading of all responses and reflections was carried out, subsequently an axial coding was performed. Thus, a longitudinal analysis was carried out throughout the different forums proposed during the course. Subsequently, an interpretation and validation of the data is carried out.

3.3.1. Coding and analysis procedure

As a first step, the data was organized chronologically according to the order of the forums, allowing us to track the evolution of participants' thinking and learning throughout the course.

For the qualitative analysis, an inductive (emergent) approach was adopted. The researchers identified recurring themes through a thematic analysis, systematically coding participants' reflections and discussions. Subsequently, axial coding was applied using Atlas.ti 9, establishing relationships between the emerging themes to identify deeper connections and patterns (Table 1). The coding process was conducted iteratively by the research team, who refined and reclassified codes through multiple rounds of review to ensure consistency, coherence, and reliability in the analysis.

Table 1

Codebook

Code	Description	Example quote
COM-3DIDE	Understanding of 3D-IDE	Understand 3D-IDE as environments that allow an immersive and three-dimensional experience in learning.
DES-TEC	Technical challenges	Found it difficult to navigate the platform at first due to my lack of familiarity with the interface.
POT-EDU	Educational potential of 3D-IDE	3D-IDE offer the possibility of creating more interactive and meaningful learning experiences.
CAM-DOC	Change in teaching practice	This course has made me rethink how I can integrate technology into my classes more effectively.
EXP-HERR	Experiences with specific tools	Using Spatial, I was able to create a virtual environment for my history class that allowed students to 'visit' historical places.
REF-APR	Reflections on personal learning	Throughout this course, I have noticed how my understanding of 3D-IDE has evolved and how this has impacted my vision of education.

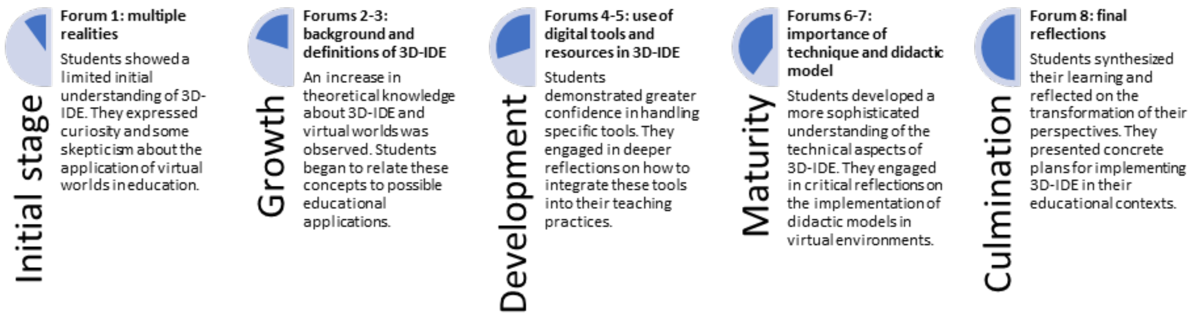
Subsequently, a longitudinal analysis was carried out to i) identify the evolution of reflections throughout the course, as well as ii) changes in the understanding and application of concepts related to 3D-IDE and VW.

i) Evolution of reflections throughout the course:

The students' contributions were reviewed from Forum 1 to the Final reflections' forum, observing how their ideas and understanding evolved (Figure 1).

Figure 1

Longitudinal evolution of reflections



ii) Identification of changes in the understanding and application of concepts:

Below is a table showing the evolution in the understanding and application of key concepts throughout the course (Table 2).

Table 2

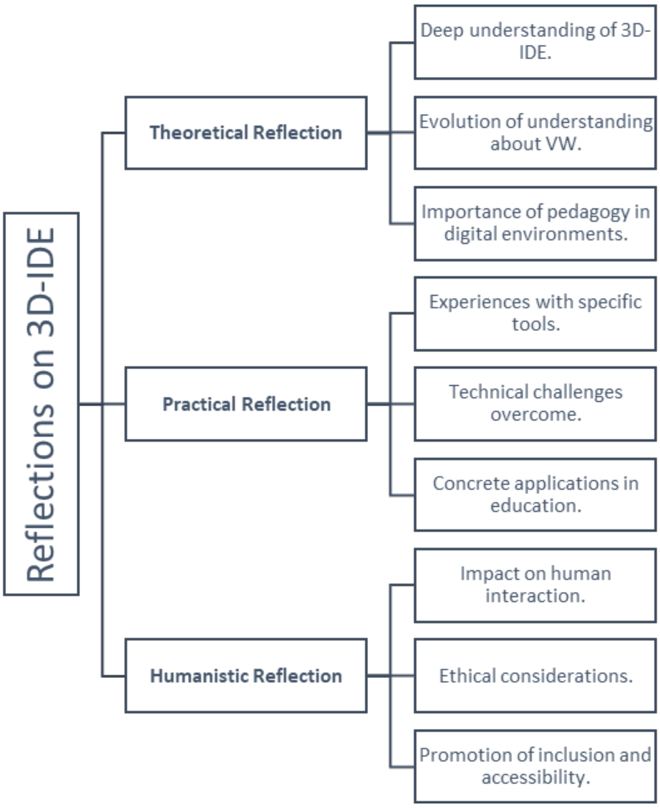
Evolution of concepts identification

Concept	Final understanding	Change in application	Learning evolution
3D-IDE	Clear understanding of 3D-IDE as immersive three-dimensional spaces	From considering them abstract to planning concrete implementations	From abstract to concrete
VW	Recognized as powerful educational tools	From spectators to content creators in virtual worlds	From passive to active
Digital tools	Familiarity with various tools (e.g. Spatial, Framevr.io)	From basic use to creative implementation in class designs	From basic to advanced
Didactic model for 3E-IDE	Understanding of the integration of technological, didactic and individual-social contexts	From following traditional models to adapting and creating models for 3D-IDE	From traditional to innovative
Technique in 3D-IDE	Recognized as an essential skill to develop	From avoiding due to complexity to seeking opportunities for technical improvement	From avoidance to mastery

This evolution shows a clear progress from a superficial and theoretical understanding towards a deep and applied understanding as well as developing practical skills and a critical vision of how 3D-IDE and VW can transform their teaching practices. Analyzing the final reflections, three main areas of reflection are identified (Figure 2).

Figure 2

Reflection of areas



To illustrate how participants integrated theoretical knowledge with practical experience, Table 3 shows specific examples of this integration.

Table 3

Integration of theoretical concept to application

Theoretical Concept	Practical Application	Participant's Reflection
Immersion in 3D-IDE	Creation of a virtual environment in Spatial	When designing my history class in Spatial, I could see how the immersion we discussed theoretically really enhances student participation. (E3)
Collaborative learning in virtual worlds	Implementation of group activities in Framevr.io	The theory of collaborative learning came to life when I saw my students interact and solve problems together in the virtual space I created. (E7)
Learning personalization	Use of adaptive tools in 3D-IDE	I truly understood the concept of personalization when I was able to adjust the virtual environment for different learning styles of my students. (E2)
Formative assessment in digital environments	Creation of interactive quizzes in virtual worlds	Formative assessment in 3D-IDE is not only possible but offers instant feedback, as we learned in theory. (E5)
Accessibility in digital education	Design of inclusive virtual spaces	Applying the universal design principles we studied allowed me to create a virtual environment accessible to all my students. (E9)

This integration between theory and practice demonstrates that participants not only acquired knowledge about 3D-IDE but also developed the ability to apply this knowledge critically and creatively in their educational contexts.

3.1.1. Data interpretation

Taking into consideration the research question about how deep theoretical knowledge in education can facilitate the effective integration of 3D-IDE through VWs in teacher training, overcoming initial technical limitations (Figure 3).

Figure 3

Overcoming technical limitations

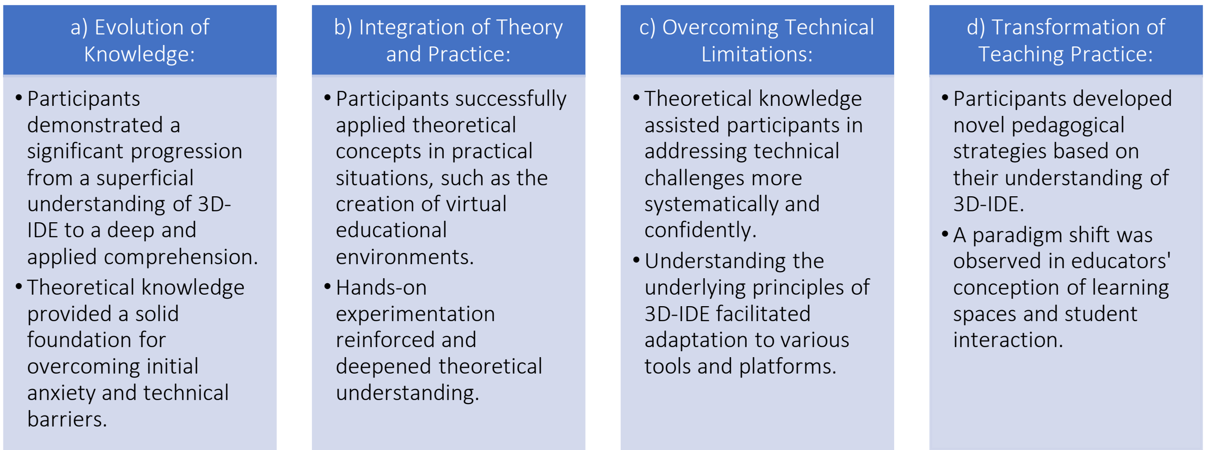
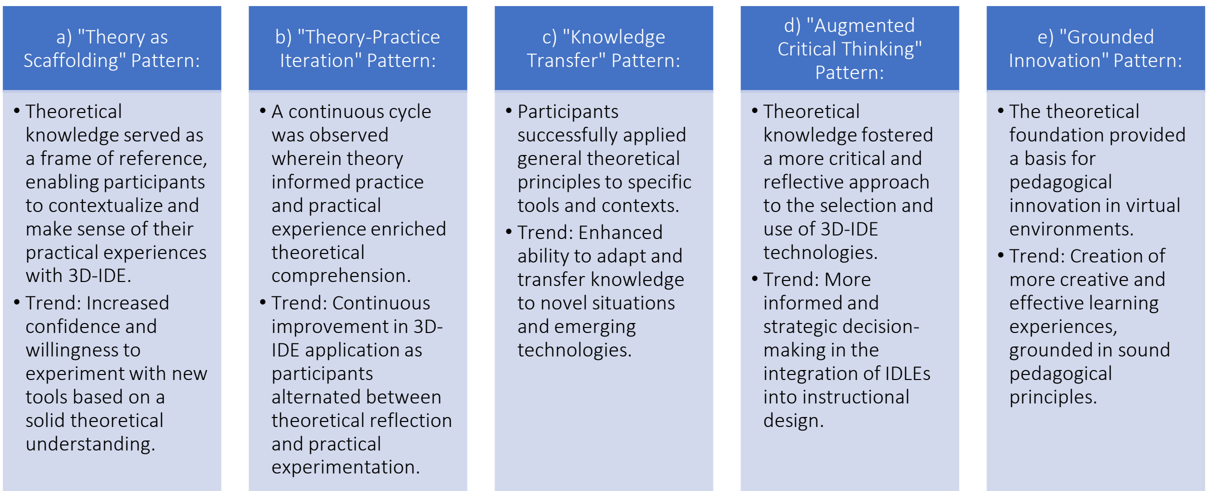


Figure 4 shows the patterns and trends in how theoretical knowledge facilitated the integration of 3DIDE technologies.

Figure 4

Patterns and trends in theoretical-practical knowledge.



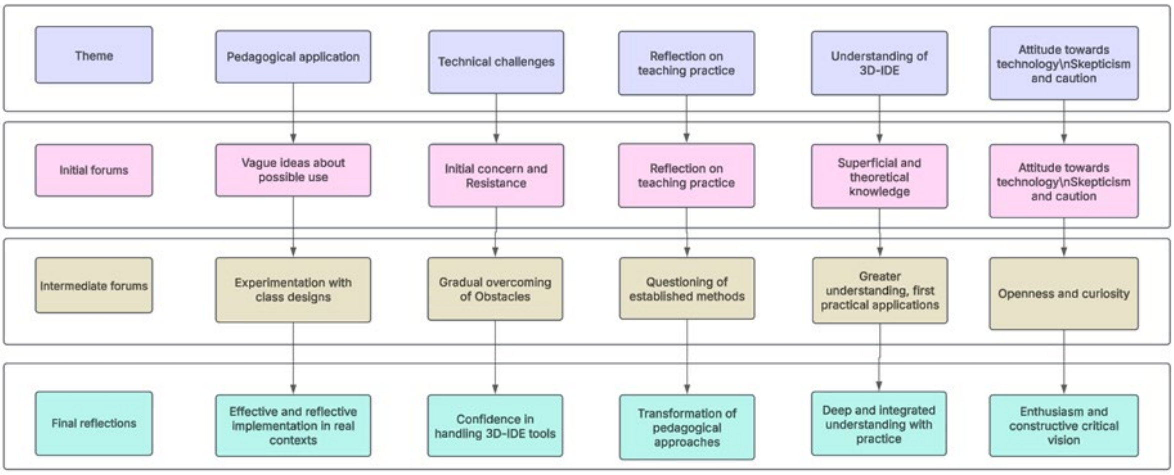
Deep theoretical knowledge in education proved to be a crucial facilitator for the effective integration of 3D-IDE technologies in teacher training. It acted as a catalyst that allowed educators to overcome initial technical limitations, providing a conceptual framework for understanding, experimenting with, and applying these technologies in educational contexts. The synergy between theory and practice not only improved participants' technical competence but also fundamentally transformed their pedagogical approaches, enabling them to harness the potential of 3D-IDE to create more immersive, interactive, and effective learning experiences. This interpretation highlights how theoretical knowledge can act as a bridge between conceptual understanding and effective practical application.

3.3.2. Validation

Data triangulation was performed between the different stages of the course (initial forums, intermediate forums, and final reflections) and b) a peer review to ensure consistency in coding and interpretation. Data triangulation between the different stages of the course was performed by comparing the data obtained in the initial forums, intermediate forums, and final reflections to verify the consistency and evolution of the identified themes. This process allows us to validate the findings and obtain a deeper understanding of how participants' learning evolved (Figure 5)

Figure 5

Data triangulation table



This triangulation shows a clear progression in participants' understanding, skills, and attitudes throughout the course, validating the findings of the thematic and longitudinal analysis.

Then, a peer review to ensure consistency in coding and interpretation was carried out according to the Kappa Index (Abraira, 2001) involving two additional researchers with experience in educational technology and qualitative analysis. The process was structured as follows:

1. Independent coding:
    1) Each reviewer independently coded a 20% sample of the data.
    2) The initially developed codebook was used.
2. Coding comparison:
    1) The researchers' codings were compared.

    2) The Kappa index was calculated.
3. Discussion and refinement:
    1) Coding discrepancies were discussed.
    2) The codebook was refined based on these discussions.
4. Recoding:
    1) The sample was recoded with the refined codebook.
5. Final verification:
    1) a. A final round of comparison was conducted to ensure a high level of agreement.

The results of the peer review yield a Kappa index of 0.76; and an agreement index after refinement of 0.89. These results indicate a high level of consistency in the coding and interpretation of the data (Abraira, 2001). The modifications made after the peer review are as follows:

1. A new code was added: "INT-TEC" (Technological Integration).
2. The definition of the "CAM-DOC" code was refined to include specific aspects of change in educational philosophy.
3. Two similar codes were merged to avoid redundancy.

The process of triangulation and peer review has strengthened the validity of the findings, ensuring a consistent and robust interpretation of the data. The high concordance in coding after peer review increases the reliability of the analysis results.

3.4. Ethical Statement

This study involved human participants, and informed consent was obtained from all individuals involved in the research. The research protocol adhered to ethical standards for studies involving human subjects and was conducted with full respect for participants' rights and confidentiality. Personal data were collected and stored securely, ensuring anonymity and confidentiality throughout the research process. The study employed Atlas.ti 9 for qualitative data analysis. The use of this technology was conducted ethically, with careful attention to avoiding algorithmic bias, protecting user privacy, and ensuring accessibility.

4. RESULTS

The presentation of results is structured in two main parts: narrative description and use of textual quotes.

4.1. Evolution of 3D-IDE Understanding

Participants showed significant progression in their understanding of 3D-IDE. Initially, most expressed superficial and primarily theoretical knowledge. As the course progressed, a transition towards a deeper and more practical understanding was observed, culminating in an effective integration of theoretical concepts with practical applications in their educational contexts. This is expressed in one reflection:

"At first, 3D-IDE seemed abstract and distant to me. Now, I not only understand their potential, but I have created my own virtual environment for my science classes." (E4, Final Reflection).

Figure 6 represents an introductory activity conducted to familiarize students with movement in a VW using the InstaVerse application. The creation of the scenario was achieved simply with a prompt. This experience primarily served for students to understand how to navigate in a virtual environment with an avatar.

Figure 6

Activity in InstaVerse

4.2. Overcoming Technical Challenges

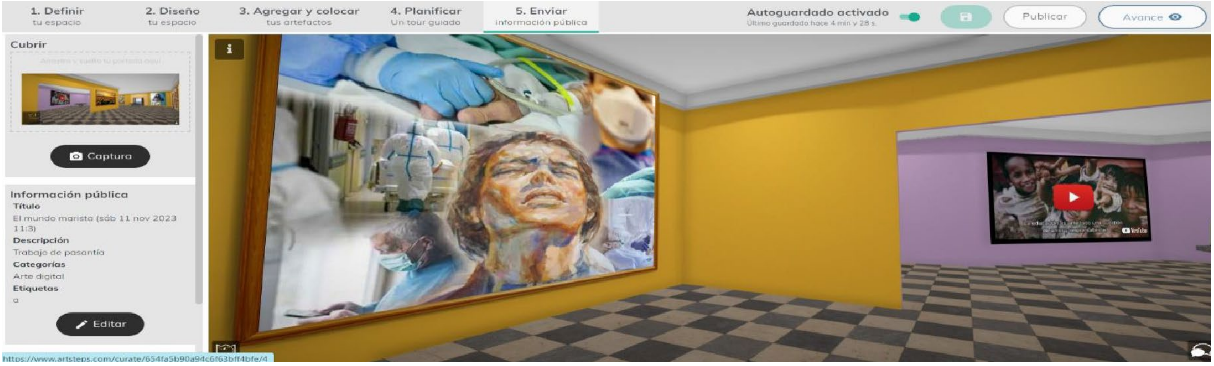
At the beginning of the course, many participants expressed concern and resistance to the technical aspects of 3D-IDE. However, through gradual exposure and guided practice, they managed to overcome these obstacles. Towards the end of the course, most participants demonstrated confidence in handling various 3D-IDE tools:

“The first time I tried to use Spatial, I felt completely lost. But with practice and course support, I can now create and modify virtual environments with confidence." (Participant E7, Intermediate Forum)

Figure 7 shows the progress of students, who had already managed to create a scenario following the specific steps provided by the platform. This process helped students understand the general procedures they should follow when developing an activity in a VW. In this case, we used ArtSteps to create a VW.

Figure 7

Activity carried out in Spatial.



4.3. Transformation of Teaching Practice

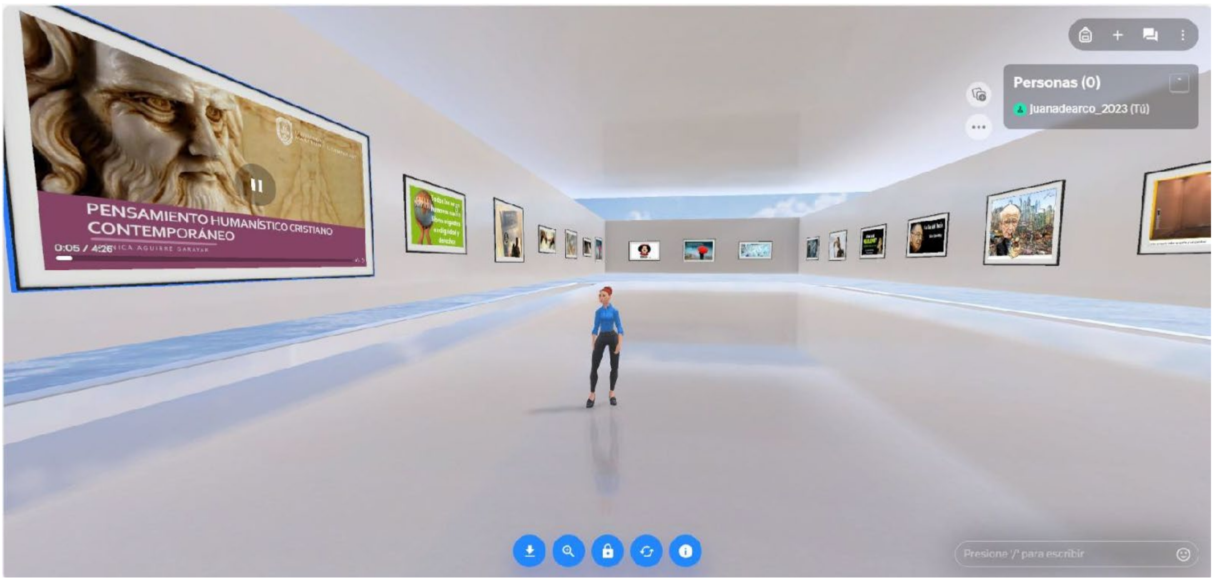
A notable evolution was observed in the way participants conceived their teaching practice. Starting from traditional approaches, they went through a phase of questioning their established methods, until reaching a significant transformation of their pedagogical approaches, creatively and effectively incorporating 3D-IDE into their teaching strategies:

"This course has revolutionized my way of teaching. Before, I was limited to PowerPoint presentations, now my students explore concepts in virtual worlds that we create together." (Participant E2, Final Reflection)

Figure 8 shows a finished work in Spatial, a multimodal, multi-platform, and interoperable platform for creating VWs. It is observed that students had already acquired the necessary digital skills to develop these VWs using the Spatial application.

Figure 8

Activity carried out in Spatial



4.4. Transformation of teaching practice

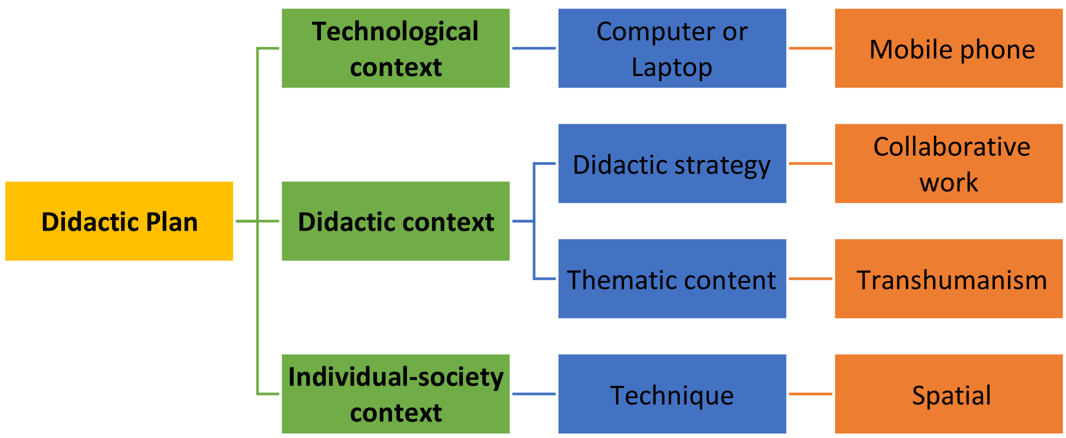
Participants' attitude towards technology in education underwent a notable change. Initial scepticism and caution gave way to openness and curiosity in the intermediate stages of the course. At the end, most participants showed enthusiasm, combined with a constructive critical vision about the use of 3DIDE in education, as expressed:

"At the beginning of the course, I saw 3D-IDE as a passing and complicated fad. Now, I'm not only excited about the possibilities they offer, but I'm also more critical and selective about how and when to use them to maximize my students' learning." (Participant E9, Final Reflection).

This idea is evidenced in Figure 9, which represents a detailed plan for a didactic activity, including the thematic content, the central idea of the activity, and how it aligns with the didactic model for 3DIDE. The choice of platform has a significant impact on the effectiveness of the didactic activity and on the development of technical skills in both the teacher and students. This image demonstrates that the knowledge acquired is not only technical but also theoretical, and shows how it can be implemented in a specific didactic context.

Figure 9

Didactic plan



5. DISCUSSION

The discussions are divided into three sections: summary of the main findings from the analyzed data, a discussion with the authors that form the theoretical corpus of this document, and limitations of the study and future research directions.

5.1. Main findings

Our study revealed a significant evolution in the understanding and application of 3D-IDE among participants. A transition was observed from initial theoretical knowledge towards practical and creative application, aligning with the findings of Farrell et al. (2022) on the importance of direct experience in VR teacher training.

The gradual overcoming of technical challenges, identified as an initial barrier (Farsi et al., 2021), was achieved through progressive exposure and guided practice, supporting the digital teacher competence framework proposed by Falloon (2020). Participants' teaching practice underwent a substantial transformation, characterized by the innovative incorporation of 3D-IDE into their pedagogical strategies. This finding aligns with Engeness's (2021) study on the development of teachers' digital identity and Nilsson and Lund's (2022) approach to digital didactic design.

Additionally, a notable change in attitudes towards educational technology was recorded, moving from initial skepticism to critical and grounded enthusiasm. This evolution is consistent with other findings on the impact of exposure to emerging technologies on the attitudes of future teachers (Taggart et al., 2023).

5.2. Discussion with framework

Our findings on the progression in understanding 3D-IDE, from theoretical to practical, emphasize the importance of direct experience in virtual reality teacher training (Farrell et al., 2022; Zhang, 2020). However, while Farrell et al. (2022) propose a reverse mentoring model, our study focuses on individual evolution, suggesting the need to investigate multiple learning approaches in 3D-IDE.

The effective integration of theoretical concepts and practical applications observed in our study complements the practical ideas proposed by Zhang (2020) for ESL (English as a Second Language) training. Nevertheless, our multidisciplinary approach contrasts, indicating the need to investigate the transferability of 3D-IDE strategies across different disciplines.

Regarding the overcoming of technical challenges, our results coincide with Farsi et al. (2021) and Laudari & Maher (2019) in identifying technical barriers as an important initial obstacle. However, our study goes further by documenting how participants managed to overcome them. As Participant E7 illustrates: "*The first time I tried to use Spatial, I felt completely lost. But with practice and course support, I can now create and modify virtual environments with confidence".*

This finding aligns more closely with Falloon's (2020) approach, who proposes a framework for developing digital teacher competence. Our results provide empirical evidence of how this competence can be built through gradual exposure and guided practice.

On the transformation of teaching practice, the observed evolution in the conception of teaching practice aligns with Engeness's (2020) study on the development of teachers' digital identity. Participant E2's quote illustrates this transformation: "*This course has revolutionized my way of teaching. Before, I was limited to PowerPoint presentations, now my students explore concepts in virtual worlds that we create together*". This finding also relates to Nilsson and Lund's (2022) approach to involving teachers in digital didactic design. This fact suggests that participants not only used technology but actively engaged in designing their digital teaching strategies.

Our findings on the change in attitude towards educational technology align with those of Taggart et al. (2023), who found that brief exposure to emerging technologies such as VR/AR led to more positive attitudes among future teachers. Participant E9's quote illustrates this change:

"At the beginning of the course, I saw 3D-IDE as a passing and complicated fad. Now, I'm not only excited about the possibilities they offer, but I'm also more critical and selective about how and when to use them to maximize my students' learning."

This nuanced attitude change, combining greater enthusiasm with a more critical perspective, aligns with the general trends observed in the literature, providing a richer and more personal view of the attitude change process. The progression from theoretical knowledge to practical application, overcoming technical barriers, and developing a critical perspective seem to be common elements in various educational contexts.

The observed differences, such as our broader focus on 3D-IDE compared to studies centered on specific technologies like VR/AR, can be attributed to the more comprehensive nature of our program. This allowed for a more holistic view of technological integration in education. Moreover, our study provides a longitudinal perspective not found in many of the cited studies, allowing observation of the evolution of attitudes and practices over time.

On the other hand, theoretically, our results suggest the need for an integrated framework to understand the adoption of 3D-IDE in education, encompassing from the development of technical skills to the transformation of professional teaching identity.

In practical terms, our findings point towards the importance of designing teacher training programs that:

1. Provide gradual exposure and guided practice with 3D-IDE.
2. Foster critical reflection on the integration of technology in pedagogy.
3. Support the development of teachers' digital identity.
4. Promote active participation in the design of digital learning experiences.

5.3. Limitations of the study and future directions

A limitation of our study is its focus on a specific context, which may limit the generalization of results.

Future research could focus on:

1) Exploring the applicability of our findings in diverse cultural and educational contexts.
2) Investigating the long-term impact of 3D-IDE training on teaching practice.
3) Examining how different academic disciplines may influence the adoption and use of 3D-IDE.
4) Deepening the understanding of the relationship between the development of teachers' digital identity and effectiveness in using 3D-IDE.

This study contributes to the field of educational technology by providing a comprehensive and longitudinal view of how future teachers develop competencies in 3D-IDE. Our findings underscore the importance of a holistic approach in teacher training that integrates the development of technical skills, the transformation of pedagogical practice, and the evolution of professional identity.

6. CONCLUSIONS

This study highlights the complex process of integrating 3D-IDE into teacher training, emphasizing the foundational role of theoretical knowledge for effective practice. Through an analysis of participants' experiences in an intensive course, we observed a notable shift from initial skepticism to a critically engaged enthusiasm, accompanied by the development of both technical and pedagogical skills.

Participants not only overcame technical challenges through guided practice but also reimagined their teaching strategies by creatively incorporating 3D-IDE. This underscores the need for training programs that go beyond technical instruction to promote reflective pedagogical transformation in the digital age.

A key outcome was the emergence of a nuanced perspective on educational technologies, moving from uncritical acceptance or rejection to informed, context-sensitive integration. This suggests the importance of cultivating "digital wisdom" among educators.

The study advocates for holistic teacher training that combines skill development, pedagogical innovation, and evolving professional identity, while encouraging critical reflection and theory-practice integration. Although the findings are context-specific and based on a small group, they provide valuable insights for future research and the design of effective professional development in emerging technologies.

Ultimately, this research contributes to understanding how theoretical grounding supports the integration of 3D-IDE, helping educators transition into critical, effective users of technology to enhance 21st-century education.

7. FUNDING

This study received no funding for its completion.

8. AUTHORS' CONTRIBUTIONS

Conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, supervision, software, validation, visualization, writing—original draft preparation, and writing—review and editing, Urith N. Ramírez-Mera; Christian Jonathan Angel-Rueda.

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Cite this work:

Angel Rueda, C. J., & Ramirez-Mera, U. N. (2025). La teoría como puente hacia la integración tecnológica: Empoderando a los educadores con mundos virtuales para una enseñanza efectiva. *Edutec, Revista Electrónica de Tecnología Educativa*, (91), 231-251. https://doi.org/10.21556/edutec.2025.91.3615